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Contribution from the Bureau of Plant Industry, Wm. A. Taylor, Chief.
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(PROFESSIONAL PAPER.)

A DISEASE OF PINES CAUSED BY CRONARTIUM PYRIFORME.

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HISTORY OF THE FUNGUS.

In 1875 Peck (10)[1] described as a new species under the name *Peridermium pyriforme* a caulicolous or stem-inhabiting Peridermium with obovate to pyriform spores from a specimen collected by J. B. Ellis (No. 2040). In 1882 Ellis issued in his North American Fungi under No. 1021 a caulicolous Peridermium which he called "*Peridermium pyriforme* on small branches of *Pinus virginiana*," and in the Ellis Herbarium, now at the New York Botanical Garden is a specimen labeled "*Peridermium pyriforme* on small branches of *Pinus rigida*, Newfield, New Jersey, May, 1890." Both of these latter specimens appear to be *Peridermium comptoniae;* at any rate, neither of them is the true *P. pyriforme* originally described by Peck. Arthur and Kern (1) in 1906 described as *P. pyriforme* Peck what is now known as *P. comptoniae*.

In 1913 the writers received from Prof. E. Bethel a caulicolous species of Peridermium on *Pinus contorta*, which they described as a

[1] Reference is made by number to "Literature cited," p. 20.

NOTE.—This bulletin discusses an important disease of pines which is now for the first time fully described. It is intended for circulation among botanists, foresters, nurserymen, State inspectors, and horticulturists.

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new species, *Peridermium betheli* (6). The type material *P. pyriforme* was not accessible at the time the article was prepared, as all of Peck's specimens were packed up and in transit from the old to the new quarters of the New York State Museum. The writers therefore had to depend upon Arthur and Kern's published statement concerning this species (1, p. 420). The spore measurements also of the typical *P. pyriforme* did not correspond, since the length of spores of the eastern species as given by Peck in his original description was too great. While this article by the writers (6) was in press, Arthur and Kern published an article (2) in which they discarded their earlier interpretation of *P. pyriforme* and admitted that there is a species of Peridermium with typical "pyriform, obovate, or oblong-pyriform spores," just as Peck had originally described it in 1875 (10), and that their original assignment of *P. pyriforme* Peck to what is now known as *P. comptoniae* was an error. They also suggested that the alternate stages of this Peridermium would probably be found on species of Comandra.

Orton and Adams (9), in 1914, published an article on Peridermium from Pennsylvania, in which they discussed *Peridermium comptoniae* and *P. pyriforme*. They described the finding of a caulicolous species of Peridermium at Charteroak, Huntingdon County, Pa., on the trunks of *Pinus pungens*, which proved to be the true *Peridermium pyriforme* of Peck. Subsequently *Cronartium comandrae* was found within 40 feet of the infected pines and the conclusion reached that this Cronartium is the alternate stage of *Peridermium pyriforme*. They also state that *P. betheli* is probably a synonym of *P. pyriforme*. In May, 1914, Arthur and Kern in a general discussion of the North American species of Peridermium inhabiting pines (3) gave the synonymy of *P. pyriforme*, a technical description, and an explanation of their change of opinion regarding the species.

In June, 1914, the writers published culture data (8) showing that successful sowings of the æciospores of *Peridermium pyriforme* had been made on *Comandra umbellata*, thus completing the life cycle of this interesting rust and proving that its alternate stage was the Cronartium found on Comandra.

MORPHOLOGY OF THE FUNGUS.

The macroscopic characters of *Peridermium pyriforme* are practically identical on all the hosts examined by the writers, but there are some differences in the microscopic characters, especially in the shape and size of the æciospores. This difference in size and shape of the spores may be due to the influence of the æcial host; that is, they may vary according to the species of Pinus which the Peridermium inhabits. In specimens of the rust on *Pinus contorta* (Pl. I,

fig. 4) from Colorado, some of the æciospores are very short and slightly acuminate, while many are ellipsoid or even globoid (Pl. I, fig. 3). In specimens on *Pinus pungens* from Pennsylvania many of the spores are nearly twice as long as those from *Pinus contorta*, the acumination is very marked, and the spores are rarely ellipsoid (Pl. I, fig. 2).

Peck's type material of *Peridermium pyriforme* is in the New York State Museum, at Albany, N. Y. It consists of a split branch 4 cm. long, 1 cm. thick at one end and 0.5 cm. thick at the other; the weak, fragile peridia barely protrude beyond the bark. The split surface of the twig is glued to the yellow paper bearing one of the legends. The specimen is in fairly good condition and most of the essential characters, both macroscopic and microscopic, can be determined from it. What appears to be the other half of this specimen is at the New York Botanical Garden, Bronx Park, N. Y., but it is much insect eaten and but little can be determined from it.

The type material at Albany bears the following legends on the box: "*Peridermium pyriforme*, Newfield, N. J. Ellis ♯2040." On the original wrapper is "*Peridermium pyriforme* on pine limbs in the spring, Newfield, N. J. .0015–.0025. No. 2040 Ellis." This legend is in two parts. The name is in Peck's handwriting, with a drawing of a spore and size of spores in pencil, while the host, location, and number of the specimen are in ink and are in Ellis's handwriting. The word "type" is not in the original legend. The following is Peck's original description of *Peridermium pyriforme* (10) and his remarks on the same:

> Peridia erumpent, large, white when evacuated, the cells subrotund, with a paler margin, marked with radiating striations, spores obovate, pyriform, or oblong-pyriform, acuminate below, .0015–.0025 inch long.
>
> Bark of pine branches. The specimen is labeled "Newfield, N. J.," but Mr. Ellis informs me that it may have been collected in Georgia and placed by accident among his New Jersey specimens.
>
> In the dried specimens the peridia are mostly compressed, about one-fourth of an inch long, and scarcely exserted above the surface of the bark. The spores are pale yellow, but probably they are more highly colored when fresh. The acumination is generally acutely pointed, and it is sometimes so elongated as to make the spore appear clavate. It is one of the most distinctive features of the species.

SYNONYMY AND DESCRIPTION OF THE FUNGUS.

Cronartium pyriforme (Peck) Hedgc. and Long, 1914, Alternate Stage of Peridermium Pyriforme.
Cronartium asclepiadeum thesii Berk., 1845, *in* Lond. Jour. Bot., v. 4, p. 311.
Peridermium pyriforme Peck, 1875, *in* Bul. Torrey Bot. Club, v. 6, No. 2, p. 13.
Caeoma comandrae Peck, 1884, *in* Bul. Torrey Bot. Club, v. 11, No. 5, p. 50.
Cronartium thesii (Berk.) Lagerh., 1895, *in* Tromsø Mus. Aarsh., v. 17, p. 94.
Peridermium betheli Hedgc. and Long, 1913, *in* Phytopathology, v. 3, No. 4, p. 251.

Pycnia unknown.

Æcia caulicolous, appearing on branches or trunks, forming lesions or fusiform swellings 2 to 30 cm. long (Pl. II, fig. 3); sori scattered or somewhat confluent in small groups, rounded or irregular, 2 to 6 mm. long by 2 to 4 mm. wide by 1 to 2 mm. high; peridium usually only slightly protruding from the bark, bladdery, subhemispherical, rupturing irregularly along the top and sides, without concolorous processes, about 2 cells thick, outer surface minutely and rather closely verrucose, inner surface also rather closely verrucose but with longer tubercles; peridial cells with a radially striate margin, not easily torn apart, those of the inner layer often irregularly compressed, walls thin, 2 to 4 μ in thickness, lumen large; cells in the upper portion of the peridium ovate, 15 to 20 by 22 to 42 μ, in the lower portion ellipsoid to ovate, 16 to 20 by 40 to 60 μ; æciospores very variable in size and shape, subglobose, obovate, ellipsoid, pyriform or even subclavate on some hosts, more or less acuminate at the basal end, occasionally at both ends (Pl. I, figs. 1, 2, and 3), 15 to 27 by 25 to 74 μ, average for 160 æciospores 21.6 by 57.5 μ, walls colorless, thicker at both ends than in the middle, 2 to 4 μ thick, rather densely verrucose with small irregular tubercles which in narrow ellipsoid spores are often arranged in irregular almost parallel lines or with a ridgelike marking, which gives the surface a reticulate appearance, no smooth spot present; cell contents of the æciospores orange yellow when fresh.

Found on *Pinus contorta* Loud., *P. divaricata* (Ait.) Du Mont du Cours., *P. ponderosa* Laws., *P. ponderosa scopulorum* Sudw., *P. pungens* Michx., and *Pinus* sp.

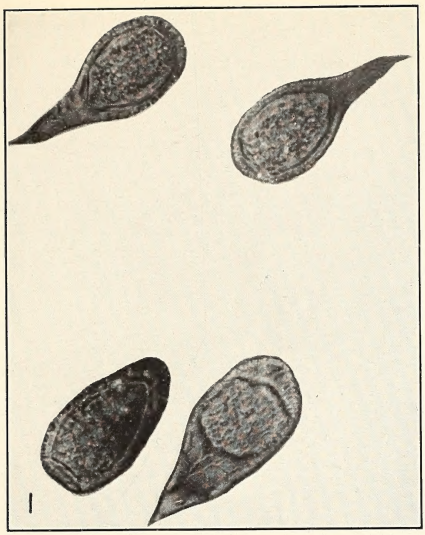
Uredinia amphigenous or hypophyllous,[1] scattered or densely gregarious, on pallid areas, pustular, 125 to 200 μ in diameter, dehiscent by a central opening or pore; peridium delicate; urediniospores broadly elliptical to globoid, 16 to 21 by 19 to 25 μ, average for 10 spores 17.8 by 20 μ, walls nearly colorless and sparsely but minutely echinulate, 1.5 to 2 μ thick.

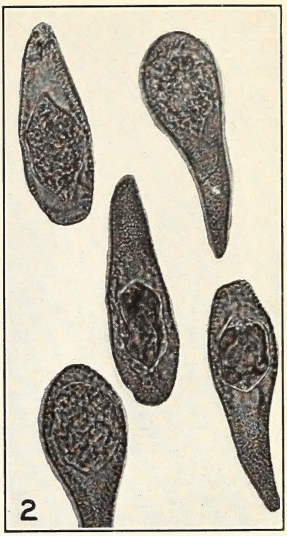
Telial columns amphigenous or hypophyllous,[1] caulicolous, cylindrical, 80 to 115 μ thick, about 1 mm. in length; teliospores oblong to cylindrical, obtuse to truncate at one or both ends, 12 to 16 by 28 to 40 μ, average for 10 spores 14 by 32.7 μ, walls smooth, nearly colorless.

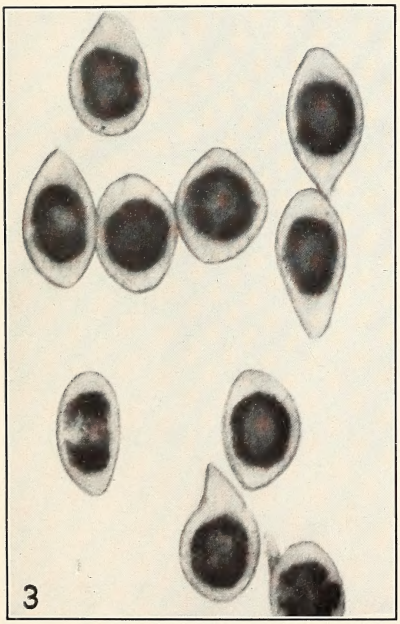
Found on *Comandra pallida* A. DC., *C. umbellata* (L.) Nutt., and *C. richardsiana* Fernald (?).

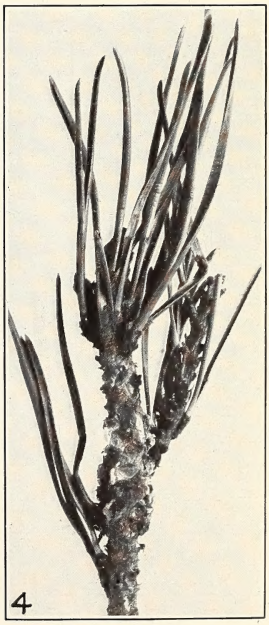
In the preceding description by the junior writer, the æcial characters (Peridermium) are taken from the specimens named in Table II on *Pinus contorta*, *P. ponderosa*, *P. ponderosa scopulorum*, and *P. pungens*. The uredinial and telial characters (Cronartium) are

[1] Amphigenous on *Comandra pallida*, hypophyllous on *Comandra umbellata*.









ÆCIOSPORES OF CRONARTIUM PYRIFORME AND A TWIG OF PINUS CONTORTA.

FIG. 1.—Æciospores of *Cronartium pyriforme*, from the type specimen on *Pinus* sp. at Albany, N. Y. (Microphotograph.) FIG. 2.—Æciospores of *Cronartium pyriforme* from *Pinus pungens*, collected near Greenwood Furnace, Pa. (Microphotograph.) These closely resemble the type. FIG. 3.—Æciospores of *Cronartium pyriforme* from *Pinus contorta*, near Eldorado Springs, Colo., from the same tree as the type of *Peridermium betheli* (microphotograph), showing the variation in the shape of the spores on this pine from those of the type specimen in figure 1. FIG. 4.—A twig of *Pinus contorta*, showing the æcia and peridia of the fungus *Peridermium pyriforme* (*P. betheli*) on a slightly swollen portion. (About natural size.)

INJURIES TO PINES PRODUCED BY CRONARTIUM PYRIFORME.

FIG. 1.—A slight hypertrophy of the trunk of a small tree of *Pinus pungens* produced by the æcia of *Cronartium pyriforme*. (About one-third natural size.) FIG. 2.—Openings produced by the rupturing of the bark of *Pinus pungens* by the maturing of the æcia of *Cronartium* (*Peridermium*) *pyriforme*. (About one-third natural size.) FIG. 3.—A twig of *Pinus contorta*, showing a fusiform swelling produced by *Cronartium* (*Peridermium*) *pyriforme* on this species of tree. Similar fusiform swellings are produced by the fungus on *Pinus ponderosa*. (About one-half natural size.)

taken from specimens of the fungus on leaves of *Comandra umbellata* obtained by inoculations with æciospores from *Pinus pungens* from Greenwood Furnace, Pa.

INOCULATION EXPERIMENTS WITH THE FUNGUS.

Table I gives complete inoculation data for this fungus on *Comandra umbellata*. Successful inoculations were made with æciospores from two hosts, *Pinus ponderosa* and *Pinus pungens*, collected from three widely separated localities in the States of Washington, California, and Pennsylvania. In each instance control plants of the same species were used, and all remained free from infection. Unsuccessful inoculations were made with æciospores from *Pinus contorta* (*Peridermium betheli*) both during 1913 and 1914. In 1914 the failure to infect might have been due to the extreme high temperature of the greenhouse at the time the inoculation experiments were performed. However, the failure for two successive seasons to infect Comandra with the æciospores from *Pinus contorta* may indicate that the rust on this host is a different species from *Peridermium pyriforme*, since the shape and size of the æciospores (*P. betheli*; Pl. I, fig. 3) from *Pinus contorta* are different from those of the type specimen of this rust (Pl. I, fig. 1). The writers, in the absence of proof from inoculations, assume for the present that these morphological differences may be due to the host and therefore are not of sufficient importance to warrant classifying *Peridermium betheli* as distinct from *P. pyriforme*.

TABLE I.—*Results of inoculations with the æciospores of Cronartium pyriforme.*

Æcial host, serial number, and locality.	Species inoculated.	Date of inoculation.	Results.			Collector.
			Uredinia.	Telia.	Degree of infection.	
Pinus contorta:		1913				
8500, Eldorado Springs, Colo.	Comandra umbellata..	June 18	.....	.....	No infection...	Bethel.
8500,[1] Eldorado Springs, Colo.	Comptonia asplenifolia	...do	.....	.....	.....do.....	Do.
8514, Allenspark, Colo.	Comandra umbellata..	June 27	.....	.....	.....do.....	Do.
Do.....	Castilleja linearis.....	...do....	.....	.....	.....do.....	Do.
Pinus ponderosa:		1914	1914	1914		
12467, Wenatchee, Wash.	Comandra umbellata..	May 27	June 5	June 28	Sparse[2].....	Fisher.
Do.....	.....do.....	May 30	June 9	July 4	.....do.....	Do.
12468, Rocky Gulch, Cal.	.....do.....	May 28	June 6	July 5	.....do.....	Boyce.
Pinus pungens:						
15444, Greenwood Furnace, Pa.	.....do.....	May 29	June 7	June 30	Very abundant.	Hedgcock.
15455, Greenwood Furnace, Pa.	.....do.....	May 30	June 10	July 15	.....do.....	Do.
Do.....	.....do.....	...do....	June 11	...do....	.....do.....	Do.
15462, Greenwood Furnace, Pa.	.....do.....	June 1	...do..	July 1	Sparse.....	Do.
Do.....	.....do.....	June 2	June 12	July 4	Abundant[3]...	Do.
Do.....	.....do.....	...do....	June 13	July 8	.....do.....	Do.
Do.....	.....do.....	June 3	...do ..	July 5	Sparse.....	Do.
Pinus contorta:						
15550, Eldora, Colo.	.....do.....	July 3	.....	.....	No infection[4]..	Do.
Do.....	Ribes longiflorum.....	...do....	.....	.....	.....do.....	Do.

[1] Type of *Peridermium betheli*.
[2] Sparse here means less than six sori.
[3] Telia immature.
[4] Inoculation made in very hot weather.

A study of Table II and of figures 1 and 2 of Plate I shows some very interesting facts. For instance, the shape and size of the spores from the type material (Pl. I, fig. 1) and those from *Pinus pungens* (Pl. I, fig. 2) are practically identical, since the range in size for 20 spores of the type is 19 to 25.6 μ by 41.6 to 73.6 μ with an average for 20 spores of 23.4 by 58.6μ, and for 20 spores from *Pinus pungens* the range is 19 to 25.6 μ by 42 to 73.6 μ with an average for 20 spores of 23.1 by 59.1 μ. This close similarity in size and shape would indicate that the type may have been on *Pinus pungens*, but this does not seem probable if the type really came from Newfield, N. J., as *Pinus pungens* has not been reported from this locality, although Britton (4) reports it as abundant 1 mile east of Sergeantsville, in Hunterdon County. It is possible that sporadic or introduced specimens of *Pinus pungens* may have been growing near Newfield at the time the collection of the type specimen of *Peridermium pyriforme* was made. The alternate stage of the rust, *Cronartium pyriforme*, on *Comandra umbellata* was collected at Newfield, N. J., by Ellis in August, 1879, and issued by him in North American Fungi under the number 1082. This indicates that the type material of *Peridermium pyriforme* came from New Jersey.

TABLE II.—*Measurements, shape, etc., of the æciospores of Cronartium pyriforme.*

Æcial host, serial number, and locality.	Measurement (microns).		Shape.	Acumination.
	Range in size.	Average for 20 spores.		
Pinus pungens:				
15462, Greenwood Furnace, Pa.	19 to 25.6 by 42 to 73.6.	23.1 by 59.1..	Obovate or pyriform to subclavate or spatulate.	Often very long (Pl. I, fig. 2).
Pinus sp.:				
Type, Newfield, N. J. (?).	19 to 25.6 by 41.6 to 73.6.	23.4 by 58.6..	Obovate to pyriform or subclavate.	Often very long (Pl. I, fig. 1).
Pinus ponderosa:				
15556, near Darby, Mont..	19 to 25.6 by 38 to 64.	22.4 by 48.6..	Obovate to pyriform or rarely ellipsoid.	Often not very pronounced.
12467, Wenatchee, Wash..	18 to 25.6 by 38 to 64.	21.1 by 51.5..	Obovate to pyriform.	Do.
12468, Rocky Gulch, Cal..	20.8 to 25.6 by 35 to 70.4.	23.9 by 54.5..	.....do.....	Do.
Pinus ponderosa scopulorum:				
12470, Crook National Forest, Ariz.	19 to 27 by 32 to 64.	21.8 by 44.3..	Ellipsoid or obovate to pyriform.	Usually very short.
Pinus contorta:				
15550, Eldora, Colo.....	15 to 25.6 by 25 to 45.	18.1 by 40.2..	.....do.....	Usually very short (Pl. I, fig. 3).
8500, Eldorado Springs, Colo.	15 to 26 by 25 to 48.	20 by 43.....	.....do.....	Usually very short.

The senior writer, during August, 1914, visited Newfield and several other localities in the same region. He found the same species of pine here that are known to occur in southern New Jersey and that probably were present at the time of the Ellis collection, viz, *Pinus echinata*, *P. rigida*, and *P. virginiana*. None of these were found by him to be diseased with the Peridermium of *Cronartium pyriforme*.

Comandra umbellata observed in a number of these localities was also free from the rust.

In 1914 the senior writer found *Pinus pungens*, *P. rigida*, and *P. virginiana* closely associated in a mixed forest near Greenwood Furnace, Pa. In this instance *Pinus pungens* was attacked by *Peridermium pyriforme* so badly that in some places more than 50 per cent of the trees were killed, and although *Comandra umbellata* plants bearing the telial form of the rust were present in abundance, no pines of either of the other species were diseased. This indicates that these two species of trees are immune and that neither can be the host for the type specimen that Ellis found at Newfield. Of the five species of pines known to be the æcial host of this fungus, not one is a strictly three-needle pine. All have either two or two to three needles in the leaf clusters. This makes it seem improbable that *Pinus rigida* was the host of the type material. *Pinus echinata* is a two to three needle pine found in southern New Jersey, and this species may have been the host of Ellis's type.

The cultural work done by the writers with *Peridermium pyriforme* Peck proving it to be the æcial stage of *Cronartium pyriforme* (Peck) Hedgc. and Long on species of Comandra completes the life history of all the caulicolous species of Peridermium as now recognized in the United States. There are four native and one introduced species and each constitutes the æcial stage of a species of Cronartium:

(1) *Peridermium pyriforme*, which is the æcial stage of *Cronartium pyriforme*.

(2) *Peridermium cerebrum* Peck is the æcial stage of *Cronartium cerebrum* (Peck) Hedgc. and Long on species of Quercus and Castanopsis. This is a well-recognized eastern species and, including its western form, *Peridermium harknessii* Moore, is the only native gall-forming Peridermium in the United States. *P. harknessii* on *Pinus radiata* Don is synonymous with *Peridermium cerebrum*, since it is associated with *Cronartium cerebrum* on *Quercus agrifolia* Née on the Monterey Peninsula in California. The other forms of *Peridermium harknessii* may not belong here, and until cultural proof of their identity with *P. cerebrum* is obtained, the forms on *Pinus ponderosa*, *Pinus contorta*, and other western pines remote from species of Quercus and Castanopsis can only be doubtfully referred here.

(3) *Peridermium comptoniae* (Arth.) Orton and Adams, a well-known eastern species, usually occurring on the pitch pine (*Pinus rigida* Mill.) in the eastern and northeastern United States, but also attacking two to three needle species, is the æcial stage of *Cronartium comptoniae* Arth. which attacks *Comptonia peregrina* (L.) Coult. and *Myrica gale* L.

(4) *Peridermium filamentosum* Peck on *Pinus ponderosa* and *Pinus contorta* is the æcial stage of *Cronartium filamentosum* (Peck) Hedgc., which attacks a number of species of Castilleja in the western United States over a wide region, ranging from the Rocky Mountains to the Pacific coast. *Peridermium stalactiforme* Arth. and Kern and *Cronartium coleosporioides* (Dietel and Holway) Arth. and Kern are synonymous with this species.

(5) *Peridermium strobi* Kleb., an introduced species, is the æcial stage of *Cronartium ribicola* Fisch. de Waldh., which attacks many species of Ribes. In Europe this Peridermium attacks several species of white (5-needle) pine. In the United States it has been found on only one species, *Pinus strobus* L.

For a number of years Prof. E. Bethel has collected from the leaves of *Ribes longiflorum* at Denver, Boulder, and elsewhere in Colorado a species of Cronartium which is apparently not identical with the European *Cronartium ribicola*. The senior writer collected abundant specimens of the uredinial and telial forms of this rust both at Boulder and Denver, Colo., in October, 1914. The telia of this Cronartium are larger, more abundant, and much more conspicuous than those of the European species. Although the fungus has been epidemic for several years on the Chautauqua grounds near Boulder, two young white pines (*Pinus strobus*) on the grounds not far from the diseased Ribes were free from the disease. This species apparently is able to winter over on Ribes plants in the uredinial form. It may yet be found that the æcial form is a Peridermium on one of our native pines.

DISTRIBUTION OF THE FUNGUS.

DISTRIBUTION OF THE ÆCIAL FORM.[1]

The æcial form of the fungus, *Peridermium pyriforme*, is widely distributed in the United States, having been found in 10 States:

FIG. 1.—Outline sketch map of the United States, showing the known distribution of *Cronartium pyriforme*. Localities where collections of the different forms of the fungus have been made are indicated as follows: ⌄, Æcial form on species of pines; ^, uredinial and telial forms on species of Comandra; ×, all forms.

Arizona, California, Colorado, Montana, New Jersey, Pennsylvania, South Dakota, Washington, Wisconsin, and Wyoming (fig. 1); and when a more careful search is made for the fungus, in the light of our present knowledge, it will no doubt be found to have a much more general distribution in this country. It has also been found in Alberta and British Columbia.

[1] All specimens cited except those marked with a star (*) have been examined by one of the writers.

DISTRIBUTION IN THE DOMINION OF CANADA.

Alberta.—On *Pinus contorta* (*P. murrayana*): * Devil's Lake, Banff, by Holway (3, p. 127), in 1907.

British Columbia.—On *Pinus ponderosa:* * Vernon, by Brittain, in 1913.

DISTRIBUTION IN THE UNITED STATES.

New Jersey.—On *Pinus* sp.: (Type) Newfield, by Ellis (2040), in 1882 (Herbarium New York State Museum).

Pennsylvania.—On *Pinus pungens:* Charteroak, by Orton and Adams, in 1913 (F. P.[1] 15129); Greenwood Furnace, by Hedgcock, in 1914 (F. P. 15444, 15455, and 15462); Petersburg, Huntingdon County, by Hedgcock, in 1914 (F. P. 15483).

Wisconsin.—On *Pinus divaricata:* * Douglas County, by Davis.

South Dakota.—On *Pinus ponderosa scopulorum:* * Rockerville, by White; Black Hills near Custer, by Hedgcock and Phillips (F. P. 15826) and by Hedgcock (F. P. 15801), in 1914.

Wyoming.—On *Pinus contorta:* Dubois, by C. E. Taylor, in 1914 (F. P. 15797).

Colorado.—On *Pinus contorta* (*P. murrayana*): * Gatos (collector not given), in 1906 (3, p. 126–127); Eldorado Springs (F. P. 8500), type of *Peridermium betheli*, Lake Eldora (F. P. 8511), Allenspark (F. P. 8502 and 8514), Arrow (F. P. 8515 and 8494), by Bethel, in 1913; Eldora (F. P. 15550), by Bethel, in 1914.

On *Pinus ponderosa scopulorum:* Monument, by Hedgcock, in 1912; Allenspark, by Bethel, in 1913 (F. P. 8504, 8505, 8510, and 8451).

Montana.—On *Pinus ponderosa:* Darby, by Weir, in 1914 (F. P. 15556).

Washington.—On *Pinus ponderosa:* Wenatchee, by D. F. Fisher, in 1914 (F. P. 12467).

On *Pinus* sp.: * Seattle, by Bonser (3, p. 127), in 1906.

California.—On *Pinus ponderosa:* Trinity National Forest, by Box, in 1912; Rocky Gulch, Siskiyou County, by Meinecke, in 1913; by Boyce, in 1914 (F. P. 12468); Mills Ranch, Goosenest Mountain, Siskiyou County, by Boyce, in 1914 (F. P. 15678 and 15680); Castella, Shasta County; Weaverville and Brown Creek, Trinity County, by Boyce, in 1914.

Arizona.—On *Pinus ponderosa scopulorum:* Crook National Forest, by Swift, in 1914 (F. P. 12470).

DISTRIBUTION OF THE UREDINIAL AND TELIAL FORMS.

Cronartium pyriforme, representing both the uredinial and telial forms of the fungus, has been collected more frequently and over a greater range of terrritory than the æcial form. It has been found in

[1] Forest-Pathology Investigations number.

Quebec and Ontario in the Dominion of Canada and in the United States in the following States: California, Colorado, Illinois, Massachusetts, Michigan, Missouri, Montana, Nebraska, New Jersey, New York, North Dakota, Ohio, Pennsylvania, South Dakota, Utah, Washington, Wisconsin, and Wyoming (fig. 1).

DISTRIBUTION IN THE DOMINION OF CANADA.[1]

Quebec.—On *Comandra umbellata.*[2]—Seven Islands, by C. B. Robinson (858, Plants of Quebec).

Ontario.—On *Comandra umbellata.*[2]—London, by J. Dearness (2443, Sydow Uredineen and 3419, Fungi Columbiani); and Point Abino, by J. J. Davis (Herbarium New York Botanical Garden).

DISTRIBUTION IN THE UNITED STATES.

Vermont.—On *Comandra umbellata:* Between Essex Junction and Burlington, by Hedgcock (F. P. 8539 and 8655); locality not given, by A. J. Grout (Herbarium New York Botanical Garden).

Massachusetts.—On *Comandra umbellata:* Magnolia, by Seymour and Earle (210–a and 210–b, Economic Fungi).

New York.—On *Comandra umbellata:* Syracuse (Ex. Herbarium L. M. Underwood); Ithaca, by H. S. Jackson (1458, Flora North America); Mount Defiance, by Peck (Herbarium New York State Museum).

New Jersey.—On *Comandra umbellata:* Newfield, by Ellis (1082, Ellis and Everhart, North American Fungi).

Pennsylvania.—On *Comandra umbellata:* Charteroak, Huntingdon County, by Orton, Adams, and Kirk (9, p. 25); Petersburg, Huntingdon County, by Hedgcock (F. P. 15637). Greenwood Furnace, Huntingdon County, by Hedgcock (F. P. 15653, 15654, and 15657).

Ohio.—On *Comandra umbellata:* Cleveland, by B. T. Galloway.

Illinois.—On *Comandra umbellata:* Oregon, by M. B. Waite (85, 134, 176, and 366).

Missouri.—On *Comandra pallida:* Emma, by C. H. Demetrio (4310, Rabenhorst-Paczschke, Fungi Europæi et Extra-Europæi).

Michigan.—On *Comandra umbellata:* Ann Arbor, by Holway (504, North American Uredinales); Ann Arbor, by F. L. Scribner; Roscommon, P. Spaulding (F. P. 15681).

Wisconsin.—On *Comandra umbellata:* Racine, by J. J. Davis; The Dells, by Underwood (Herbarium New York Botanical Garden).

Nebraska.—On *Comandra pallida:* Dismal River, by Webber (784, Fungi Nebraskenses); Hat Creek basin, by Webber (776, Fungi Nebraskenses); Lincoln, by R. J. Pool (F. P. 17045).

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[1] All specimens here listed are in the mycological collections of the United States Department of Agriculture unless otherwise noted.

[2] These species probably should be *Comandra richardsiana* Fernald, since the collections were made in the range of *C. richardsiana* and out of the range of *C. umbellata* as now recognized.

Wyoming.—On *Comandra pallida:* Big Horn Mountains, by Williams and Griffiths (298–a, West American Fungi); Bear Lodge Mountains, by Griffiths and Carter (298, West American Fungi); Centennial, by E. T. and E. Bartholomew (3705, Fungi Columbiani); near Medicine Bow River, by A. Nelson (1257, Herbarium University of Wyoming).

South Dakota.—On *Comandra pallida:* Iroquois, by F. A. Williams (1914, Fungi Columbiani); Black Hills, near Custer, by Hedgcock and Phillips (F. P. 15827 and 15828).

North Dakota.—On *Comandra pallida:* Beaver Lake, by J. F. Brenckle (78, Fungi Dakotenses).

Colorado.—On *Comandra pallida:* Boulder, by F. E. and E. S. Clements (542, Cryptogamæ Formationum Coloradensium); south of Yuma, by H. L. Shantz, U. S. Dept. Agr. Plant-Disease Survey; Short Creek, Custer County, by T. D. A. Cockerell (99 and 104, Ellis Collection in Herbarium New York Botanical Garden); Soldier Canyon, by J. H. Cowen (168, Ellis Collection); La Veta, by C. A. Crandall (283, Ellis Collection); Pagosa Peak, by C. F. Baker (22, Plants of Southern Colorado); also by F. S. Earle (120, Herbarium New York Botanical Garden); Sangre de Cristo Mountains near Westcliffe, by Hedgcock (F. P. 8082); Steamboat Springs, by Hedgcock (F. P. 3873 and 3889); Monument, by Hedgcock (F. P. 3792, 3839, 15948, and 15950); Palmer Lake, by Hedgcock and Bethel (F. P. 3794 and 3819); Boulder, by Hedgcock (F. P. 15885); Golden, by Hedgcock (F. P. 15888); Palmer Lake, by Hedgcock (F. P. 15907 and 15948); Monument Nursery, by Hedgcock and Pierce (F. P. 15950).

Utah.—On *Comandra pallida:* Locality not given, by M. E. Jones (Herbarium New York Botanical Garden).

Montana.—On *Comandra pallida:* Helena, by F. D. Kelsey; Sandcoulee, by F. D. Kelsey (2419, Ellis and Everhart, North American Fungi); Sandcoulee (80, Montana Flora) and Helena (61, Parasitic Fungi Montana), by F. W. Anderson; Missoula, by Hedgcock and Kirkwood (F. P. 8021).

Washington.—On *Comandra pallida:* West Klickitat County, by W. W. Suksdorf (176, Flora of Washington).

California.—On *Comandra umbellata:* Shasta Springs, by W. C. Blasdale (6 North American Uredinales), by M. A. Howe (101, Fungi California), Herbarium New York Botanical Gardens; Mills Ranch, Siskiyou County, by Boyce (F. P. 15796); Integral Mine, Shasta County, by Boyce; Rocky Gulch, Siskiyou County, by Meinecke; Weaverville and Brown Creek, Trinity County, by Boyce; Goosenest Mountain, Siskiyou County, by Boyce and Rider.

DISSEMINATION OF THE FUNGUS.

Cronartium pyriforme is disseminated by means of its three spore forms—viz., æciospores, urediniospores, and teliospores—each form playing an important rôle in maintaining the succession of generations between pine trees and Comandra plants. The process of infection with this species of rust does not differ materially from that of the white-pine blister rust (12).

The æcia on the table mountain pine (*Pinus pungens*) in Pennsylvania mature from the middle of May to the latter part of June. Farther north on the jack pine (*Pinus divaricata*) they bear their spores somewhat later in the season. On the lodgepole pine (*Pinus contorta*) and the western yellow pine (*Pinus ponderosa*) from Colorado to Wyoming, the period of maturity is from the middle of June to the middle of July. In each region they develop earlier on slopes of southern exposure and at lower altitudes.

The æciospores are discharged in great abundance for a day or two and with lessened abundance for about a week longer. They infect any Comandra plants with which they come in contact. The leaves are most commonly infected, but occasionally the stems and floral parts are attacked. The infection near diseased pine is usually very abundant, decreasing rapidly as the distance increases. An abundant infection from æciospores has not been noted for more than 200 feet from the æcial center, when it is located on small pines. When large pines are diseased in the upper limbs, the distance that the æciospores are blown is greatly increased, and the zone of infection is therefore extended very much, and on mountain slopes may reach the distance of nearly 1,000 feet. This inoculation of Comandra plants by æciospores may well be designated as a primary infection, and that by urediniospores, described in the following paragraph, as a secondary infection.

In 8 to 10 days from the time of inoculation by æciospores the uredinia appear on the leaves of the infected Comandra plants and urediniospores begin to be produced. These are blown about by winds and inoculate other Comandra plants. This secondary infection greatly extends the area of diseased plants. A second crop of uredinia develops in from 8 to 10 days from these secondary infections. This process continues throughout the growing season. It is possible that as many as six or more generations of uredinia may be thus produced in one season, and the fungus may spread several miles in this manner. It is by this method of infection that the fungus spreads the greatest distance in nature, which explains why the form of fungus on the Comandra plants is more common than on the form of pines.

In about 15 days the telial columns develop from the uredinial sori on the Comandra plants. As each column grows older it gradually elongates, and the development of teliospores progresses outward

along the column with its growth. The period of teliospore formation for each telium is from one to two weeks. The teliospores germinate in situ as fast as they mature, without being detached from the telial columns. As each teliospore germinates it develops a basidium, which when typical bears four sporidia. The sporidia borne on each basidium, however, are usually less than four. The sporidia become detached as soon as mature and are carried away by even the slightest breeze. They readily infect the younger part of pine trees, thus completing the life cycle of the fungus. From observation it appears probable that germinating sporidia usually gain entrance into the tissues of the pines through wounds or in wound callus where young cells are exposed. Inoculations with another species, *Cronartium cerebrum*, on pine trees (*Pinus virginiana*) without wounds have failed, while at the same time, other conditions being similar, they were successful in wounds.

Since each generation of uredinia on Comandra plants is followed within a few days by one of the telia, there is a continual production of sporidia from the time the telia first appear till the end of the growing season. This greatly extends the period of possible infection for pines, a period which must be from two to four months, depending upon the length of the growing season in pines, which varies not only at different altitudes and in different latitudes, but also from season to season.

It is highly probable that the various spore forms of this fungus, especially the æciospores from the pines, may be carried about on the bodies of birds and of the smaller animals. In this manner they could be carried even to greater distances than is possible by wind dissemination.

If young pines in nurseries should become infected, the danger of a much wider dissemination of the fungus than has already taken place in nature is at once possible, with man as the agent. Under conditions such as occur in many localities both in the eastern and the western United States it would be easily possible for the pines in nurseries to become badly infected, owing to the abundance of Comandra plants in the vicinity.

EFFECT OF THE FUNGUS ON ITS HOST PLANTS.

EFFECT OF THE ÆCIAL FORM ON PINES.

The immediate effect of the æcial form, *Peridermium pyriforme*, varies in different species of pines and on the same species under different conditions. When young lodgepole pines or western yellow pines are attacked, either on the trunk or limbs, there commonly develops a slightly swollen area in the region of the infection. If the infected area encircles the trunk, as it usually does, a spindle-shaped or fusiform swelling may result (Pl. II, fig. 3), which varies

from an inch to more than a foot in length. In case of *Pinus pungens* (Pl. II, figs. 1 and 2), fusiform swellings are not so common as in case of *Pinus contorta* and *Pinus ponderosa*. Swelling is commonly not very evident in very young trees of any of these three species. The bark layers are usually thickened in the portions where the rust mycelium is present. So far as can be ascertained from field observations the æcia may not appear until three or more years after infection takes place.

The development of the peridia at the maturity of the æcia ruptures the bark of the diseased areas, forming numerous openings (Pl. II, fig. 2) which reach to the inner layers of the cambium. As a result the death of the cambium layer may take place, due apparently to excessive evaporation of water through the lesions. The part of the tree attacked usually is either girdled and killed outright or it is partially girdled and a canker is formed. Young pines are very commonly girdled and killed during the same season the æcia are produced. In its effect on pines, *Peridermium pyriforme* must be classed with *P. strobi* and *P. filamentosum* and be ranked as one of the most destructive species of Peridermium in North America.

In a region adjacent to Greenwood Furnace, Huntingdon County, Pa., the senior writer, during June, 1914, took notes on the number and condition of pines (*Pinus pungens*) diseased with *Peridermium pyriforme*. Again, in autumn, the condition of the same trees was noted, and it was found that of 50 diseased pines upon which the æcia had been found in June, 29 (58 per cent) were dead from the girdling effect of the fungus.

These had apparently died shortly after the æcia fruited, as dead leaves were still clinging to the branches of the trees. The pines examined were small, varying in height from 4 to 10 feet, and in diameter at the ground from 1 to 4 inches. A similar effect was noted during the autumn of 1914 on a smaller number of young pines (*Pinus ponderosa*) in the Black Hills near Custer, S. Dak.

J. S. Boyce, of the Office of Investigations in Forest Pathology, has reported this fungus on the yellow pine (*Pinus ponderosa*) in Klamath, Shasta, and Trinity National Forests in California.[1] This report states that in the Klamath National Forest—

> The parasite produced spindle-shaped swellings at the point of infection on the yellow pine, usually on the main stem but occasionally on the branches. These swellings varied from 2 inches to a foot in length.
>
> The fungus on yellow pine undoubtedly kills that portion of the main stem or branch of the tree above the point of infection. A number of small trees were found to have been killed. Each of these bore one or more spindle-shaped swellings on the stem. A volunteer (shoot) had then appeared while a new infection had occurred just below the point where the volunteer joined the main stem. A repeated killing of this kind causes a strikingly deformed tree.

[1] Boyce, J. S. Notes on *Cronartium pyriforme*. Unpublished report submitted December 7, 1914.

The largest infected tree found was 12 feet high and 3 inches in diameter at breast height, approximately 22 years old, with the infection occurring 5 feet from the ground. In another area here 10 saplings killed by the fungus, with only one living uninfected tree, were found.

One diseased area of *Pinus ponderosa* at Mills Ranch on the north slope of Goosenest Mountain in the Klamath National Forest was described by Boyce, which contained at least a hundred acres. The largest tree diseased by the fungus in this area was 8 inches in diameter at breast height. Spindle-shaped swellings were common, but more especially on the younger, smaller trees. The girdling effect and death of the host tree in the parts above the point of infection were very much in evidence in this area. Small trees apparently were girdled and killed much sooner than older trees. Wounds caused by some gnawing animal, presumably the porcupine, were common on trees in areas where the fungous disease occurred. In one of the diseased portions of the forest a sample plat was established by Boyce and a count of the healthy, infected, dead, and dying trees of *Pinus ponderosa* was made. The result was as follows: Out of 314 trees in the plat, 153 (48.7 per cent) were apparently healthy, 52 (16.5 per cent) were plainly diseased by the fungus, 3 (0.9 per cent) were dying, and 106 (33.7 per cent) were dead from the effects of the fungus. In the words of the report:

Over 50 per cent of the total number of trees of the sample plat had been infected, and nearly two-thirds of the total number infected had already been killed. There is, of course, a possibility that the death of some of these might have resulted from other causes, but only those trees were included which I was certain in my mind had been killed by the fungus.

Boyce's data corroborate those taken by the senior writer both in Pennsylvania and South Dakota.

Reporting concerning an area of diseased *Pinus ponderosa* along Browns Creek in Trinity National Forest, Boyce says:

There were many dead trees, undoubtedly killed by the fungus, with spindle-shaped swellings on the main stems. On living infected trees the æcia were sporulating (June 27, 1914), but not very abundantly, not to be compared with the sporulation found at Rocky Gulch on May 20. One infected sapling was found in which the major portion of the bark had been destroyed either by wood rats or porcupines.

Where the trunk is not girdled, cankers or catfaces are occasionally formed by the death of a portion of the cambium. In such cases the continued presence of the fungus in the live tissues beyond the dead area stimulates their growth, and the fungus may fruit a number of times before the tree is killed. Catfaces on the lodgepole pine (*Pinus contorta*) and on the western yellow pine (*Pinus ponderosa*), however, are more commonly produced by another species of rust, *Peridermium harknessii*.

Peridermium pyriforme, when it infects the trunk of a pine tree, may spread from the trunk to such limbs as spring from a point near

the center of infection or, vice versa, may spread from the point of infection on a limb to that part of the trunk adjacent to the diseased area on the limb. In this it resembles *P. filamentosum* (5) and the fusiform type of *P. cerebrum* (*P. fusiforme*) (7, p. 248). Such instances in the case of both *P. pyriforme* and *P. filamentosum* on *Pinus ponderosa* have been observed by the senior writer in Colorado and Wyoming and noted by Spaulding (11, p. 28, 34) in the case of *Peridermium strobi* on white pines in the northeastern United States.

EFFECT OF THE UREDINIAL AND TELIAL FORMS ON COMANDRA PLANTS.

The effect of the uredinial and telial forms of the fungus, *Cronartium pyriforme*, on Comandra plants can not be separated into two distinct sets of symptoms, since the two forms are produced on the same area of tissue, the one following the other in a few days. Both the uredinia or the telia may occur on either surface of the leaves, as well as on the younger portions of the stems, and occasionally on the floral parts.[1] In badly infected plants there is a decided shortening of both the stems and the leaves in their growth, so much so as to change the entire aspect of the plants. This is usually accompanied by a slight chlorosis of the leaves. Where the infection is slight, the diseased spots on the leaves are usually a lighter green color than the uninfected portions. Late in the growing season the reverse coloration sometimes takes place, and the chlorophyll is retained longest in light-green areas in the leaves where the mycelium of the fungus is found, even after the remainder of the leaf has become yellow from fall coloration.

In badly infected Comandra plants defoliation takes place prematurely; that is, before drought, frost, or cold weather bring it about. No data have been obtained as to the final effect of the rust on Comandra plants. The effect, however, is decidedly stunting, and plants infected badly for several seasons would undoubtedly be killed.

ERADICATION AND CONTROL OF THE FUNGUS.

One of the most serious facts in connection with the prevalence of *Peridermium pyriforme* in some portions of the western United States is the danger of introducing it into localities now free from it through the shipment of trees in the work of artificial reforestation. For this purpose nursery stock is often shipped long distances. The forest nursery if situated in mountain regions is apt to be in a locality where Comandra plants are common. Since these serve as host plants for both the uredinial and telial forms of the fungus, their presence may lead directly to the infection of the young pines in the nursery and indirectly to the infection of localities hitherto free from the disease.

[1] In *Comandra pallida* this is the case. In *Comandra umbellata* the uredinia and telia are found uniformly on the under surface of the leaves.

If it were possible to distinguish all of the diseased trees at the time of planting, it would be an easy matter to discard them and thus prevent the further spread of the disease. Such, however, is not the case, since the disease may not become evident until three or four years after the young trees are infected and until after they are planted in the forest. This being the case, other means for the control of the disease must be adopted. The most feasible plan to prevent further infection in the nursery and the subsequent dissemination of the disease through infected nursery stock appears to be the elimination of all Comandra plants in the vicinity of the nursery.

In order to protect the nursery from infection whenever the disease is present in adjacent forests, all diseased pines that can be found within a radius of at least half a mile from the nursery should be cut down. These can be selected most easily by a person familiar with the fungus, at the time the æcia mature in the pines. As previously stated, this period varies from the middle of May till in August, depending upon both the latitude and the altitude of the locality. This cutting-out process should be repeated each year until no more diseased trees can be found in the proposed neutral zone.

The elimination of all diseased pines will not suffice, however, absolutely to control the disease in the nursery when Comandra plants are in the vicinity, since it is quite certain that the fungus can spread by the urediniospores from one Comandra plant to another for long distances in one season. By this means the disease could be carried from diseased pines outside of the neutral zone or belt of removal to the young pines in the nursery. To protect the nursery against infection from this fungus all Comandra plants within 1,000 feet of the outer boundaries of the nursery should be removed by digging them out.

Comandra plants are herbaceous perennials and spread primarily by means of seeds and secondarily by means of underground runners. The secondary method is the more common. The seeds, being edible, are much liked by birds and rodents, and it is possible that they may be carried by these animals to a considerable distance from the original place of growth, thus starting new plant colonies. The eradication of Comandra plant colonies will be difficult, owing to the numerous underground runners, any of which are liable to be broken off and left in the ground to start new plants. It will no doubt be necessary to dig up the plants repeatedly before they can be completely eradicated. All species of Comandra are parasitic and derive part of their food supply from other plants by a direct attachment of the smaller side roots of Comandra to the roots of the host plants. It is not yet known how many species of plants are thus parasitized, but several widely different species are attacked. Species of Vac-

cinium are commonly parasitized. This subject is now being investigated by the writers.

The recommendations here given are based on observations made in forests by the senior writer and not on actual experiments. An attempt to control this disease as recommended here has been planned and will probably be carried out in 1915. Until it is certain that the neighborhood of a nursery is free from this fungus, shipment of stock to uninfected forests should be avoided.

The spraying of pines with Bordeaux mixture or other fungicides for the prevention of infection by *Cronartium pyriforme* can not be recommended until it is known that this method is effectual in controlling the disease.

The spraying of Comandra plants with a poisonous substance to kill the foliage and tender shoots at the time they might be infected from the æcial form of the fungus on pines should prevent the immediate spread of the disease to the pines in adjacent nurseries. This spraying should be done as soon as the leaves of the Comandra plants are fully developed and before the plants bloom. This would probably be from the latter part of May to the middle of July, depending on the altitude and the latitude of the locality. Should the Comandra plants send forth new growth later in the season it might be necessary to spray a second time. Spraying should be repeated each year as long as any Comandra plants remain alive. Where young pines are present, this method could not be used without killing them, and the uprooting of the Comandra plants is recommended for such areas.

Mr. H. R. Cox, Agriculturist of the Office of Farm Management, Bureau of Plant Industry, has prepared a circular letter giving directions for the use of plant poisons in killing vegetation. This circular follows, more complete directions being obtainable from the office mentioned upon request:

For several years this office has been making tests of various chemical plant poisons for killing all vegetation in such situations as driveways, pathways, tennis courts, railroad rights of way, and similar places. It appears that of the substances there are three that are better than any of the rest, namely, arsenite of soda, common salt, and some form of petroleum. The best one of these for each case will depend upon conditions. It seems to be more economical usually to make a number of comparatively light applications for the purpose primarily of killing the foliage rather than one heavy one to affect the roots as well as the tops.

In the case of most kinds of vegetation excepting the grasses, and especially for vegetation of a broad-leafed character, arsenite of soda is highly effective. The commercial grade may be obtained at about 25 cents per pound from some of the wholesale chemists. If large areas are to be treated, it can be made at home more cheaply by boiling 1 pound of white arsenic and 2 pounds of sal soda in a gallon of water until a stock solution is formed. From 10 to 20 pounds of the commercial arsenite of soda or from 7 to 14 pounds of the white arsenic in the home-mixed formula, either one diluted to make from 50 to 100 gallons of solution, is sufficient to kill most of the foliage on 1 acre.

Common salt may be applied dry, provided it is fine grained and is scattered very uniformly. Salt may be applied more uniformly, however, if it is made into a saturated solution (1 pound to 1½ quarts of water). The latter is usually the most satisfactory form. It should be used at the rate of from 3 to 5 tons per acre, depending upon the character and rankness of the vegetation.

Of the petroleum products, fuel oil is about the most satisfactory, although this is sometimes difficult to obtain, and then only in barrel or tank-car lots. Near the oil fields, crude oil as it comes from the well can be obtained cheaply and is quite satisfactory. The petroleum products should be applied at the rate of from 300 to 400 gallons per acre. If small areas are to be treated, so that the matter of expense is of little consideration, kerosene may be used. The petroleum products seem to be the most effective of all when applied to narrow-leafed vegetation, such as grass; salt seems to be the next in effectiveness on such plats, and arsenic third.

A spraying outfit is best for applying liquid material, excepting the salt brine, with which a sprinkling can or sprinkler will do faster work. The petroleum products are very hard on the rubber parts of spraying outfits, but it is necessary to use a sprayer in that connection on account of economy of application; with very small areas where economy is not to be considered the oils can be applied through a sprinkling can.

In the forest under our present conditions and market values it is not best to advise methods of elimination so expensive as have been given for the protection of nurseries. In badly infected areas of young forest trees, all diseased trees should be cut out whenever possible. This often can be done by the forest officer without very great expense, owing to the small size of the trees. In lumbering, trees diseased with catfaces or cankers should not be left for seed trees, as their vitality has been lowered and they will not produce as good a crop of seed as more healthy trees, and it is also highly probable that the viability of the seed produced by such trees is lower than that produced by more healthy trees. Again, trees with such cankers are often capable of producing æciospores around the border of the cankers and if allowed to remain for seed trees would become centers of infection for the younger generations of trees in the new forest.

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